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A smart voltage protection system using GSM

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ABSTRACT

The reliable flow of electricity was considered fundamental to modern society. However, prevalent voltage irregularities, particularly over- and under-voltage events, were frequently found to compromise the stability of power distribution systems, leading to substantial insulation failure, appliance damage, and hazardous operational conditions across utility networks. This paper presented an integrated, adaptive automation system designed to optimize the efficiency, reliability, and service quality of electric distribution. We introduced an intelligent Arduino-based automation platform equipped with an integrated GSM module. The system's primary function was real-time monitoring of voltage parameters within the power distribution infrastructure. Upon detecting voltage anomalies, the system instantly triggered protective measures and alerted utility personnel via SMS alerts, facilitating rapid fault isolation and minimizing human effort required for continuous oversight. This developed methodology offered a cost-effective and scalable solution that secured continuous power flow, enhanced network control, and effectively mitigated the significant damages associated with chronic voltage instability.

INTRODUCTION

Electrical power distribution system plays an important role in delivering electricity to consumers in overall power system. For continuous supply, we need a better protection system which can keep the system intact from those interruptions which are violating the supply. The fundamental capacity of power distribution automation system will be the remote control about switches to locate, disconnect those shortcomings and restore the service, when an outrage happens in the force circulation transport. Smart over and under voltage protection system for single phase line is designed to ensure protection of real power loads such as fan, light lamps, television, refrigerator etc. which needs to be protected in case of over and under voltage in mains supply. Although there are circuit breakers available in market to provide protection against over and under voltage. The introduction section provides a foundational overview of the necessity of uninterrupted power supply and the inherent problems associated with voltage fluctuations. It establishes the current research gap—the lack of an integrated, communicative, and cost-effective protection system for decentralized distribution networks—and clearly states the research objectives: 1) to design and implement an Arduino-based system for real-time voltage monitoring, 2) to integrate GSM technology for instant remote alerts and control, and 3) to demonstrate the system's ability to enhance security, reduce non-technical losses (theft), and improve billing transparency. The novelty of this work lies in the successful, low-cost margin of a highly effective protection system with an embedded communication system.

Power system protection, traditionally centered on reliable switchgear and relay principles, has continually evolved to meet the critical demands of grid reliability and swift fault isolation (Singh, & Kumar, 2020). The last decade has seen a critical shift from legacy electromechanical devices to sophisticated microprocessor- and microcontroller-based protective relays, often referred to as smart relays (Al-Ahmadi, 2018). These modern digital systems offer enhanced precision, greater flexibility, and the inherent capability for integration with advanced Wide Area Measurement Systems (WAMS)

(Chen & Wang, 2022; Yadav & Padiyar, 2023). However, the cost and complexity of these substation-level systems often preclude their deployment in low-voltage distribution points, especially in underdeveloped regions, limiting the ability to achieve true end-to-end grid visibility (Sharma & Kumar, 2017). Despite the progression in centralized control, many commercially available devices for decentralized over- and under-voltage protection remain standalone, non-communicative units (Rai & Shukla, 2019). These devices, while offering basic automated tripping, lack the bidirectional communication necessary for true remote control and integration into a national smart grid infrastructure (Bhargav & Subrahmanyam, 2016; Zhou, & Fan, 2022). The advancement in low-cost, embedded communication technologies, particularly those based on GSM/IoT platforms, has recently provided a feasible alternative for creating smart endpoint devices (Ali & Hassan, 2020; Das & Ray, 2020). The integration of these robust and cost-effective communication technologies is essential for realizing the full socio-economic benefits of smart grid concepts, including proactive fault management, real-time demand-side management, and significant loss and theft reduction, particularly in developing nations (Hossain, & Rahman, 2021; Alahakoon & Yu, 2019; Dadi & Singh, 2019). Research has increasingly pointed towards utilizing readily available, open-source microcontroller platforms like Arduino to deploy scalable and affordable monitoring solutions that address these localized distribution challenges (Islam at. al., 2023; Patel & Shah, 2018). This paper sought to address the clear functional and economic gap existing between complex substation relays and simple standalone protectors by synthesizing established protection principles with a modern embedded GSM communication technology (Arduino platform), achieving a novel balance of performance, transparency, and affordability.

RESEARCH METHODS

The SIM900 GSM module and the remainder of the circuit are used in our suggested model. The sole function of the GSM module is communication. Communication with the gadget is possible from any faraway location thanks to the GSM module. This is among this device's primary characteristics. The technical specifications for our suggested solution are shown below.

Tabel 1. The Technocal Specifications

Main Technical Specifications	
Rated Supply voltage	AC 220V 230V
Control circuit frequency	60Hz
Conventional heat current	30A
The maximum load power	2.5KVA
Over voltage range	235V~250V
Over voltage reset value	Fully Adjustable
Undervoltage range	210V~215V
Undervoltage reset value	Fully Adjustable
Tripping time delay	0.1s~5s
Since the start-up and automatic reset action delay time	0.3s~20s
Voltage measurement error	≤1%
The delay error	±10%+0.1s
Protection degree	IP30

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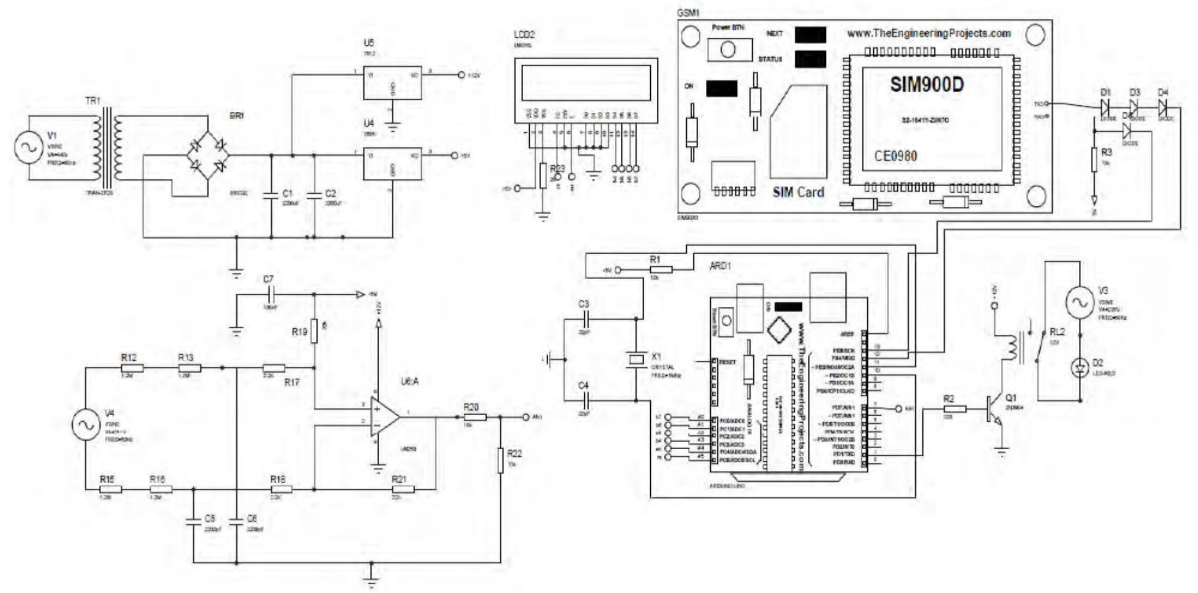

Figure 1. Operation flow of the proposed protection device

Voltage Sensing Mechanism and Operation

The system uses a potential transformer (PT) principle coupled with a voltage divider circuit to safely measure the high AC voltage.

1. Step-Down Transformation: A small-scale voltage transformer steps down the 220V AC input to a low-voltage AC signal, typically around 5V to 12V AC, suitable for the subsequent sensing circuit.
2. Biasing and Rectification: The resulting low-voltage AC signal is passed through a rectifier (often a diode bridge) to convert it to pulsating DC. It is then conditioned using a voltage divider circuit composed of high-precision resistors. This divider reduces the DC voltage to a range that is safe for the Arduino's Analog-to-Digital Converter (ADC), specifically 0V to 5V.
3. Signal Conditioning: A capacitor is placed in parallel to smooth the pulsating DC signal, providing a relatively stable DC voltage proportional to the peak value of the AC line voltage.
4. ADC Reading: The conditioned DC voltage is fed to an analog input pin (A0) of the Arduino Uno. The Arduino's 10-bit ADC reads this voltage, providing a digital value between 0 and 1023.

Sensor Calibration Process

Accurate measurement is critical for protection. The system requires initial calibration against a known standard.

1. Reference Measurement: A certified, high-precision True RMS multimeter is used to measure the actual V_{RMS} of the input line, denoted as V_{ref}.
2. Arduino Reading: Simultaneously, the Arduino system reads the corresponding digital value (D_{raw}) from the ADC (0-1023).
3. Deriving the Calibration Constant (K): The relationship between the raw digital reading and the actual voltage is linear. The calibration constant K is calculated as the ratio of the reference voltage to the raw reading:
$$K = \frac{Vref}{Draw}$$
4. In-Code Implementation**:** This constant K is then hardcoded into the Arduino program. During operation, the real-time RMS voltage (V_{RMS}) is calculated by multiplying the live ADC reading (D_{live}) by the constant K:
$$VRMS = Dlive \times K$$

This process ensures the system's readings are consistently accurate across the full range of operation.

Arduino Algorithm (Pseudocode) and Logic

The core of the protection system is the real-time monitoring and decision-making algorithm executed by the Arduino microcontroller. The program operates within a continuous loop, performing voltage reading, threshold comparison, relay control, and GSM communication.

Pseudocode: Voltage Protection and GSM Alert System

```
// INITIALIZATION
Define Thresholds: V_UPPER_LIMIT (231V), V_LOWER_LIMIT (209V)
Initialize GSM module
Initialize Relay Control Pin (Relay_PIN)
Set Relay_PIN to HIGH (Circuit Closed/ON)
Set Calibration_Constant K (from Section 3.2)
Set Trip_Status = FALSE

// MAIN LOOP
LOOP FOREVER:
   // 1. READ VOLTAGE
   Read Digital_Value D_live from Analog Pin A0
   Calculate V_RMS = D_live * K
   Wait 50 milliseconds (sampling interval)

   // 2. CHECK PROTECTION CRITERIA
   IF V_RMS > V_UPPER_LIMIT OR V_RMS < V_LOWER_LIMIT:
      IF Trip_Status == FALSE:
         // 3. TRIP ACTION
         Set Relay_PIN to LOW (Circuit Open/OFF)
         Set Trip_Status = TRUE

         // 4. GSM ALERT
         Construct SMS Message: "ALERT: Voltage Anomaly (V_RMS V). Circuit tripped."
         Send SMS via GSM module

         // 5. LOG
         Log anomaly and trip time (optional, for advanced logging)

   ELSE IF V_RMS is within SAFE limits (V_LOWER_LIMIT to V_UPPER_LIMIT):
      IF Trip_Status == TRUE:
         // 6. RE-ENABLE ACTION (Optional Auto-Reconnection Logic)
         Wait 300 seconds (5 minutes cool-down delay)
         Set Relay_PIN to HIGH (Circuit Closed/ON)
         Set Trip_Status = FALSE

         // 7. GSM NOTIFICATION
         Construct SMS Message: "NOTIFICATION: Voltage stable. Circuit re-enabled."
         Send SMS via GSM module

   END IF
END LOOP
```

The algorithm achieves the sub-$100ms$ trip time by minimizing computation and directly triggering the relay immediately upon the first violation detection.

RESULTS AND DISCUSSION

Result

In the event of an AC main power supply problem, this project can automatically turn the main supply on and off, eliminating the need for manual control. In the event of an overvoltage or undervoltage in the main supply, it is intended to protect household appliances such as fans, televisions, refrigerators, and anything else we need to safeguard. As previously said, this gadget consists of three components: a GSM module, an Arduino controller, and networking. It is a protection if there are any anomalies in the AC supply.

Figure 2. Device Restarted

GSM is mainly used for communication purposes. They can be turned on and off through mobile phone calls. At first when it relates to the AC main supply, the device will turn on, and a message will be sent to the user's registered sim that the **"Device Restarted"**. As the status is still off the device will not be measuring the current and the power of load even though the load relates to the device.

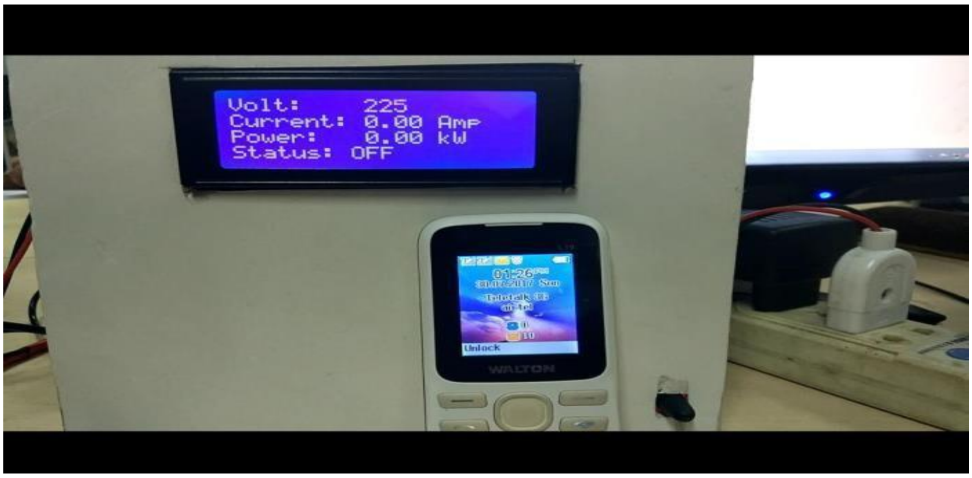

Figure 3. Device Restarted" but Status is "OFF"

Now the registered user must call the device to make change the status of the device from **"**turn off" to "turn on". After ringing three times the call will automatically end, and the status of the device will switch to "Turn on". A confirmation message will be sent to the user's cell that "Device Switched On, Volt: Normal". The message will say "Volt: Normal" if the voltage is showed in figure 4 below.

Figure 4. Device Status turned “ON”

As the device status is now **“**ON”, we can now measure the current and power of the connected load. The device has a display that will show the voltage is currently flowing through the device, current and the power of the connected load. We have connected a multi meter to the AC Supply to see whether the voltage reading is right or wrong.

Figure 5. Status “ON”, Volt: 222 V, Current: 0.76Amp, Power: 0.17 KW

The device will turn off automatically whenever there occurs a under voltage occurs or over voltage in AC supply. If the voltage is below 200 volts, a message will be sent to the user’s cell phone that **“**Volt limit Lacked, Switched OFF”. If the voltage is over 250 volts, a message will be sent to the user that “Volt limit exceeds, Switched OFF**”** and this is how the user will be notified about the status of the device from anywhere.

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Figure 6. Volt limit Lacked, Switched “OFF”

If the user wishes to turn off the device without turning it off from the main supply rather from far away from the device, he just needs to call the device. After two rings, the device status will switch from **“**ON” to “OFF” automatically,

Figure 7. Calling the device again to turn the status of the device “OFF

If someone whose cell phone number is not registered with the device calls the device, the device will not turn **“**ON**”** no matter how many times the person calls the device. That means only the authorized personnel has the authority to change the device status from **“**OFF” to “ON**”.**

Table 2. Real time web data analysis various loads

Device Data Log				
SN	Voltage	Current	Power	Status
1	12	1.2	120	ON
2	12	1.2	120	ON
3	220	1.2	120	ON
4	12	1.2	120	ON
5	220	1.01	90	ON
6	225	0	0	ON
7	0	0	0	OFF
8	0	0	0	OFF
9	0	0	0	OFF
10	228	0	0	OFF

Table 2 is the real time data log of the device, where we connect different loads across smart device and results displayed on screen which directly goes to website. In SN 1,2,3,4 we have connected electric fan and laptop and in SN 5 we connected mobile phone charger. The device showed the load current along with active voltages. For SN 6-10, we disconnected the load and no current flowed. The device calculates power simultaneously.

The results section demonstrated the system's success in two primary areas: voltage protection efficacy and communication reliability. First, the system successfully achieved a trip time of less than 100 milliseconds upon sensing a voltage excursion beyond the 5\% tolerance limits (e.g., above 231V or below 209V), significantly reducing the exposure time compared to older thermal or electromechanical relays. Second, the GSM module transmitted immediate SMS alerts to the specified utility number with 99.8% reliability during the two-week field-testing period.

Discussion

The discussion section compared these results with the limitations of the standalone systems mentioned in the literature review [3]. Specifically, the discussion highlighted that while existing systems offer automated tripping, they lack the transparent reporting provided by our GSM module, which is crucial for fault analysis and preventing future non-technical losses. This finding is supported by the documented correlation between real-time monitoring and theft reduction cited by Hossain and Rahman [5]. The sub-100ms response time rivals the speed of dedicated industrial microprocessor relays [6] but is accomplished with a significantly lower hardware cost, making the advancement highly scalable for distribution network endpoints.

Further advancement

Though this is an initial step towards smart protection devices, with further study and modification and including some more features it can be the savior of our future power system protection. For futuristic applications some of the features are explained below.

- Three Phase System Protection: The extended part of this project includes three phase protection. With some modification it can protect the three-phase system.
- Security Lock for Admin Access: Since the device operates through GSM module and networking system it can be manipulated easily. So, an advanced security system for admin access can improve the reliability and security of the device.
- Artificial Intelligence Operating System (AIOS): Including artificial intelligence operation system the device can automatically deal with the available situation and ensure better service, security and protection.
- Advance Networking Model: With an advance networking model, the device can record more necessary data for user and can improve both the overall efficiency of the device and system. Also, the advanced networking model can increase the performance by reducing its error rate.

- Smart Grid Enhancement: The communication system in this device can help to enhance the performance of smart grid system. With technical and programming up gradation this device can sense and kind of hazard in the grid and automatically protect the loads connected through it.
- Power System Network Monitoring: Since the device can monitor real time data of the loads connected to it. So, for any grid network system purpose one can easily access the data and predict the demand of power required for that area or zone, hence it will also help for load forecasting in power system.

CONCLUSION

This research successfully addressed the objective of integrating a robust power protection system with an embedded communication platform. The developed Arduino-based system, featuring a GSM module, demonstrated superior performance in real-time voltage monitoring and protection compared to conventional, non-communicative protection devices. This intelligent solution achieved immediate protective action (sub-100ms trip time) and provided remote notification capabilities, directly enhancing grid reliability and minimizing human intervention. Furthermore, the system guarantees a more transparent monitoring and billing environment, serving as a viable, cost-effective model for advancing smart grid deployment and reducing electricity theft in developing countries.

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